Research Proposal

Intended school: School of Knowledge Science, Japan Advanced Institute of Science and Technology

Name: XXX

Research Topic: Finding a Model of Plant Evolution

1. Objectives

The main aim of this research is to contribute to the answer to the following question: what are the *basic design considerations for creating a synthetic model of the evolution of living systems* (i.e. an "artificial life" system)? It can also be viewed as an attempt to elucidate the logical structure (in a very general sense) of biological evolution. However, since there is no adequate definition of life, I will concentrate only on several specific issues of open-ended evolution, such as symbiogenesis, Tierra model, α-Universes, Koza's System, etc.

To this end, I plan to *develop a model*, which can simulate the evolution of plants (e.g. rice plant evolution), based on biological analyses in order to combine the biological researches with the traditional approaches to find a better solution.

2. Research background and research context

2.1 Background

Artificial Life (ALife) is the study of man-made systems that exhibit behaviors characteristic of natural living systems. It complements the traditional biological sciences concerned with the analysis of living organisms by attempting to synthesize life-like behaviors within computers and other artificial media. By extending the empirical foundation upon which biology is based beyond the carbon-chain life that has evolved on Earth, Artificial Life can contribute to theoretical biology by locating life-as-we-know-it within the larger picture of life-as-it-could-be.

Artificial Evolution is a classic topic of Artificial Life. Researchers in artificial evolution typically pursue one of the following goals:

First, they are interested in understanding the principles of biological evolution; in the spirit of the synthetic methodology, the understanding of biological phenomena can be greatly enhanced by trying to mimic or model aspects of the biological system.

Second, the other main goal is to use methods from artificial evolution as optimization procedures or design methods. In many areas, evolutionary algorithms have proved their usefulness, especially for "hard" problems.

2.2 Research context

John von Neumann, in the late 1940s and early 1950s, devoted a considerable time to the question of how a complicated machine could evolve from simple machines. Specifically, he wished to develop a formal description of a system that could support self-reproducing machines which were robust in the sense that they could with stand some types of mutation and pass this mutation on to their offspring.

Lionel Penrose, in 1957, developed a series of mechanical models of self-reproduction, which bear some similarity to von Neumann's kinematic model. Furthermore, he also considered a self-reproduction scheme, which was more like the relatively simple template-reproduction mechanism of the nucleic acids (DNA and RNA) than von Neumann's full self-reproduction architecture. The reproduction of structures in Penrose's Models can be seen as the result of a self-inspection process; more elaborate schemes for reproduction by self-inspection have been described by Laing in 1977 and Ibánez in 1995.

Steen Rasmussen and his colleagues, in the early 1990s, introduced a system with self-reproducing components. They conducted a series of experiments using a general approach they named "Coreworld". More recently, in 1994, John Koza has proposed a system of self-replicating programs using a slightly different approach.

Open-ended Evolution refers to a system in which components evolve new forms continuously, rather than grinding to a halting when some sort of 'optimal' or stable position is reached. Nils Aall Barricelli was the first person to actually run artificial evolution experiments on computers. He introduced the concept of symbiogenesis in his work as an additional requirement for his organisms. In addition, Barricelli conducted some experiments in which the individual symbioorganisms were also decoded in to a strategy for playing a simple game.

There have been some more recent works in the artificial life community on the subject of symbiogenesis. Some of issues involved in incorporating biogenesis in artificial life models were discussed by Daida in 1996, and studies of general conditions under which symbioses may occur were reported by Bull and Fogarty in 1995. Some practical implementations incorporating the indeas of symbiogenesis have been successful at solving several particular problems (e.g. Ikegami and Kaneko, 1990; Numaoka, 1995).

Taking into account the modeling of evolution, in 1976, John Holland proposed a collection of models, which he referred to as the "α-Universes". The α-Universes was implemented in the form of a computer program by McMullin in 1992. After the α-Universes, Holland developed the "Echo" model of complex adaptive systems in 1995 and Larry Yeeger described a system called PolyWorld in 1994. PolyWorld modeled many features of biological life, such as a simple "metabolism", a nervous system, and vision.

Early attempts of allowing variable-length genomes in an artificial life simulation were described by Robert Collins in his Ph.D. thesis in 1992. In this work, an organism's genome encodes a neural network, which controls its behaviors. Along the same lines, Inman Harvey worked on extending the theory and the design of the standard genetic algorithm to allow open-ended evolution to increase overtime by permitting the length of genomes.

Finally, it is worth noting that some of the most spectacular examples of artificial evolution that have been produced to date model co-evolutionary processes (Hillis, 1990; Sims, 1994; Miller and Cliff, 1996; Floreano, 1998). In these studies, the success of organisms in one population depends upon the success of organisms in another co-evolving population. However, these studies have all been geared towards producing organisms, which are good at performing a particular task. To this end, the co-evolving organisms are still generally competing in some pre-specified game, and they are not given the potential for truly open-ended evolution in which they could develop entirely new games to play.

3. Methodology and Plan

3.1. Methodology

Some of the most important methodological issues concern with the scientific use of artificial life techniques. The important point is that simulations should be based upon explicit theories and assumptions if they are to be of scientific value.

The emergence of parasites and similar phenomena in Tierra, which was introduced by Ray in 1991, might appear to be suggestive of a close parallel between this system and biological evolution. However, the appearance of parasites in Tierra turns out to be dependent on some specific aspects of the system's design, rather than on any particular general principles. Further more, closer analysis reveals that it only requires a single mutation of the original ancestor program to produce a parasite; this was reported in Ray's original paper. These facts suggest that the claims concerning with the relationship between artificial life models and the real world should be treated with caution.

In my view, Tierra and many other recent contributions to artificial life can be regarded as constituting an "exploratory stage" of the subject, in which the potential of the new techniques has been investigated. This is a useful stage, and indeed is a normal aspect of any experimental science. Further progress towards scientific knowledge should be based upon the development and testing of properly formulated theories.

To achieve this end, I will continue to find a methodology that can be viewed as:

- Investigate the most recent works on artificial life and evolution (theoretically as well as using practical data) to find their merits and drawbacks.
- Develop a model of natural evolution to overcome the drawbacks and, at the same time, maintain the merits of those works. So far, most of researches on artificial life are mainly based on mathematical models. In the recent years, along with researches in bioinformatics, some biological data have been revealed. I will incorporate the mathematical models with the real data to clarify the relationship between artificial life models and the real world.
- Conduct experiments and improve the model to achieve better results.

3.2. Plan

In order to build a model of natural evolution, I intend to study in order to acquire a good knowledge of biology for a period of about three months first. Next, I will spend three months investigating the previous researches in the literature to understand the modern approaches with their advantages and drawbacks.

In the following, I will start my research, build the model, conduct experiments, and analyze the experimental results to find the answer to the question (about twelve months). The rest of time will be used for writing papers to report the research results, improving the model, and writing the doctoral thesis.